

**HIGH RESOLUTION IMAGING OF CIRCUMSTELLAR DISKS AT MILLIMETER
WAVELENGTHS**

Grant NAG5-11777

Annual Report #3

For the period 1 March 2004 through 28 February 2005

Principal Investigator

Dr. David J. Wilner

December 2004

Prepared for

**National Aeronautics and Space Administration
Goddard Space Flight Center, Greenbelt, MD**

**Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138**

<p>The Smithsonian Astrophysical Observatory is a member of the Harvard-Smithsonian Center for Astrophysics</p>
--

December 29, 2004

Annual Report – Grant NAG5-11777

David J. Wilner

We summarize progress on our program to use high angular resolution imaging of thermal dust continuum emission at millimeter and submillimeter wavelengths to probe the structure of protoplanetary disks and debris disks around nearby stars.

In the past year, we have accomplished the following:

1. We gave an invited review talk on “Millimeter and Submillimeter Observations of Protoplanetary Disks” at the 2nd Terrestrial Planet Finder/Darwin International Conference on Dust Disks and the Formation, Evolution and Detection of Habitable Planets, in July 2004 [1]. This talk presented a synthesis of several aspects of our Origins supported work on protoplanetary disks.
2. We are close to submitting for publication an analysis of the “low resolution” Very Large Array 7 millimeter observations of the disks around a sample of about a dozen T Tauri stars. These observations used the mature capabilities of the Very Large Array 7 millimeter system, repeating our early efforts. These observations spatially resolve nearly all of the sources, which breaks the degeneracy of optical depth and dust properties, and therefore provides strong evidence for grain growth, the first step toward planet formation. Figure 1 shows a compilation of the images, as presented at the 2nd Terrestrial Planet Finder/Darwin International Conference in July 2004 [2].
3. We submitted a paper on Very Large Array 7 millimeter observations of the compact disk in the IRAS 16293-2442B system, which is thought to be among the youngest protostars known [3]. These observations have angular resolution of 70 mas, or about 10 AU. A detailed, self-consistent, accretion disk model indicates a disk radius of only 26 AU. This discovery supports the notion that protoplanetary disks start small and grow with time, although other explanations for the compact disk size cannot be ruled out, including gravitational instability in the outer parts.
4. We published a paper describing Submillimeter Array observations of the disk around the TW Hya, the closest classical T Tauri star [4]. This paper includes the first ever interferometric images of a disk in the 850 μ m wavelength band of dust continuum and the CO J=3-2 line. The continuum emission is well fit by the irradiated accretion disk model developed in our earlier studies of the longer wavelength dust emission. The

CO line emission shows clear Keplerian rotation, and also provides constraints on the gas heating. We have successfully proposed for new, higher resolution, higher quality observations with the full Submillimeter Array, scheduled for the first quarter of 2005.

5. We attempted further observations of protoplanetary disks in the southern hemisphere with the Australian Telescope Compact Array. This telescope provides access to many very interesting sources that are difficult or impossible to observe with northern facilities. We had previously detected several sources in a short snapshot survey, and the main goal of these observations was to confirm and improve these detections. Unfortunately, the upgrade of the millimeter system to 5 antennas was delayed until after the end of good winter weather season. We observed only two sources, with marginal results. We have proposed for more observations next year.
6. We published two papers that consider the role of a "Square Kilometer Array" (SKA) for imaging protoplanetary disks [5,6]. We led the campaign to make protoplanetary disk science a key project for this new facility, an international next generation radio telescope, highly ranked in the decadal survey among ground based initiatives. Because planet formation is not a traditional topic for centimeter radio astronomy, this very important area had been overlooked in SKA planning. The SKA can play a pivotal role in understanding terrestrial planet formation by extending the techniques we are developing with Origins support to higher resolution and sensitivity, imaging dust emission from the inner regions of disks at sub-AU scales, revealing structures whose motions can be tracked in synoptic studies. The resulting "Cradle of Life" theme has become a highly touted part of the SKA science case (see <http://www.skatelescope.org>).
7. We made observations with the Plateau de Bure Interferometer of the debris disk around HD107146, recently recognized as the first known debris disk around a true young Solar analog. Unfortunately, these observations did not detect any millimeter emission from the disk, perhaps because it is smooth on the scales probed by these observations. This result was a surprise, and we plan further analysis of these data in conjunction with possible source models.
8. We presented the first results on debris disks with SHARC II, a new bolometer camera at the CSO optimized for a wavelength of $350\ \mu\text{m}$, at the January 2004 AAS meeting in Atlanta [7], and we are writing up these results for publication. The ring structure of the debris disk is seen more clearly than ever before. We believe the asymmetries within the ring may be most plausibly explained by the presence of a massive planet. We successfully applied for more time at the CSO to image another debris disk, and these observations are scheduled for January 2005. At this short submillimeter wavelength, the angular resolution of the CSO is 9 arcsec sufficient to resolve structure in the most

nearby systems. But the emission is faint, requiring very deep integrations in the very best weather on Mauna Kea.

We have exercised our option to a one-year extension of the grant period, at no cost to NASA, in order to complete the publication of data in hand, and to allow for observations that have been delayed.

REFERENCES

1. **Wilner, D.J.** 2004, "Millimeter and Submillimeter Observations of Protoplanetary Disks", the 2nd Terrestrial Planet Finder/Darwin International Conference, <http://planetquest1.jpl.nasa.gov/TPFDarwinConf/proceedings/sessionC/Wilner.pdf>
2. Rodman, J., Chandler, C., Henning, Th., Mundy, L., **Wilner, D.**, Dullemond, K. 2004, "Clear Signs of Dust Grain Growth in Disks around T Tauri Stars", the 2nd Terrestrial Planet Finder/Darwin International Conference, <http://planetquest1.jpl.nasa.gov/TPFDarwinConf/proceedings/sessionC/Rodman.pdf>
3. Rodriguez, L.F., Loinard, L., D'Alessio, P., **Wilner, D.J.**, Ho, P.T.P. 2005, "IRAS16293-2442B: An Isolated, Compact Protoplanetary Disk in a Class 0 Object", *ApJ*, submitted
4. Qi, C., Ho, P.T.P., **Wilner, D.J.** et al. 2004, "Imaging the Disk around TW Hya with the Submillimeter Array", *ApJ*, 616,L7
5. **Wilner, D.J.** 2004, "Imaging Protoplanetary Disks with a Square Kilometer Array", *New Ast. Reviews*, 48, 1363
6. Lazio, T. Josph W., Tarter, Jill C., **Wilner, D.J.** 2004, "The Cradle of Life", *New Ast. Reviews*, 48, 985
7. **Wilner, D.J.**, Dowell, C.D., Holman, M.J., Kuchner, M.J. "The Debris Disk around ϵ Eridani at 350 microns" *BAAS*, 203, #130.03

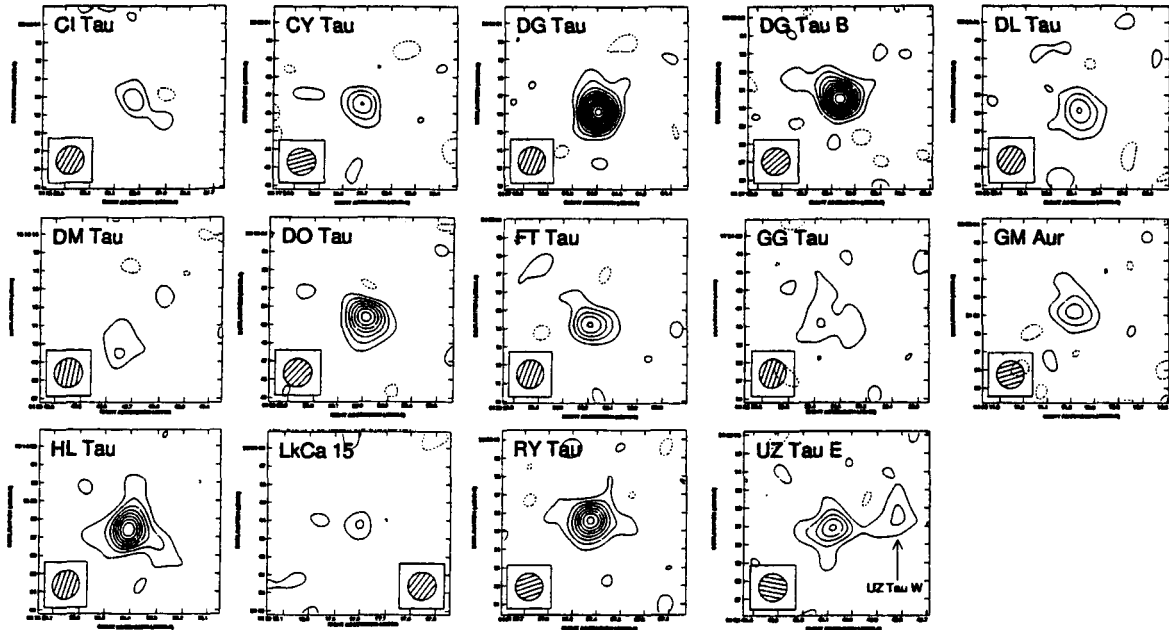


Fig. 1.— Images of 7 millimeter emission from a sample of low mass stars in the Taurus molecular cloud, observed with the Very Large Array. The typical synthesized beam size is 1.5 arcsec, and the typical rms sensitivity is about 0.2 mJy. These images show dust emission from the disks around the stars. In nearly every image, the emission has been spatially resolved, which indicates the dust opacity is low. The spectral indices of the dust emission determined by comparison with observations at shorter millimeter wavelengths indicate the presence of millimeter sized dust grains, an important step toward planet formation.